Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

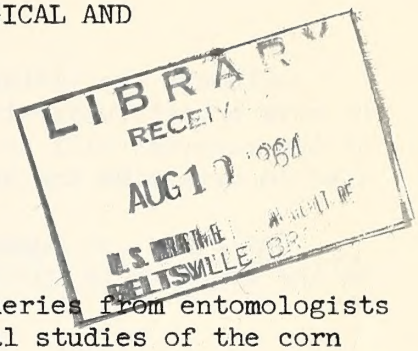
R31

July 1964 ARS-33-94

ARS 33-94

United States Department of Agriculture
Agricultural Research Service

BASIC SEMICONDUCTOR CIRCUITRY FOR ECOLOGICAL AND BEHAVIORAL STUDIES OF INSECTS



by Philip S. Callahan
Entomology Research Division

I have prepared this report primarily to answer queries from entomologists about electronic techniques I have used in my ecological studies of the corn earworm, Heliothis zea (Boddie). In these studies, conducted for the most part at the Southern Grain Insects Research Laboratory at Tifton, Ga., during 1962-63, I utilized certain standard circuits, which I modified slightly. These original circuit designs can be found in the publications on electronics marked with an asterisk in the References Cited section on page 9 of this report.

This report includes descriptions of basic semiconductor circuitry for accurate measurements of an insect's environment and behavior; some methods for using Ohm's law to calculate resistance in meter-recording circuits; an explanation of the characteristics of photoconductive and photovoltaic cells, thermistors, and pressure-sensitive microducers; and a presentation of schematics and examples of many simplified semiconductor circuits I have used to study the environment and behavior of the corn earworm moth.

From the first discovery by Edmond Becquerel in 1839 of the photoemissive effect, until after 1930 when the theoretical studies by Hertz, Elster, Geitel, et al. had been accomplished, little practical use was made of the unusual solid-state phenomena, most probably because of the small amount of electrical current they generate or control. In the years since World War II, however, the development of solid-state physics has progressed so rapidly, and semiconductors are now employed in such a diversity of circuits, that it is almost impossible to remain abreast of the field. New uses for control and recording mechanisms are limited only by a person's imagination, and entomologists, once they become acquainted with the subject, are apt to increase the list of uses indefinitely.

Recording

The circuits described here are for read-out on a microammeter or a microammeter-galvanometer recorder such as the small, inexpensive, 50- or 100-microampere Amprobe® recorder (fig. 9d).[1/] There are over 200 manufacturers of

1/ Mention of a proprietary product in this publication does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture, and does not imply its approval by the Department to the exclusion of other products that may also be suitable.

various special-type recorders in all price ranges. The electrical characteristics and working mechanisms of these recorders are listed in the extremely useful Recorder Manual by Aronson (1962). The inexpensive Amprobe instrument is a pressure-sensitive, paper type, with a lift-plate stylus, and with a 5-second action and chart speeds up to 15 inches per hour. The 50-microampere model used in these circuits has a 7400-ohm meter resistance.

Ohm's Law

Although the voltage and currents involved are of low value, it is important to have a basic understanding of electrical resistance so that the meter mechanism of the recorder will not be damaged when setting up the circuits. Ohm's law is used to determine the value of the resistances in the meter circuit.

Ohm's law, in common terms, states that the current in amperes (I) is equal to the pressure in volts (E) divided by the resistance (R) in ohms; that is:

$$I = \frac{E}{R}, \text{ or transposed,}$$

$$R = \frac{E}{I}, \text{ or } E = IR.$$

In a series circuit the total resistance is the same as the individual resistance, i.e.,

$$R_T = R_1 + R_2 + R_3, \text{ et cetera.}$$

Thus, using a 1.4-volt mercury battery, the current that would flow through a microammeter recorder with a 7400-ohm resistance is:

$$I = \frac{1.4 \text{ V}}{7400 \text{ ohms}} = 0.000189 \text{ amp.}$$

Since 1 microampere (μa) = 1/1,000,000 of an ampere, then 0.000189×10^6 = 189 μa. As the maximum deflection of the meter is only 50 μa, it is easily seen that the recorder in series with a 1.4 battery would be damaged by drawing more than three times its rated capacity.

If we insert a resistor (for example 30,000 ohms) in series with the meter resistance, we decrease the current across the meter coil (fig. 1A). We then have a series curcuit where:

$$I = \frac{E}{R_1 + R_2} = \frac{1.4 \text{ V}}{37400 \text{ ohms}} \quad I = 0.0000374 \text{ amp.} \times 10^6 \text{ or } 37.4 \text{ μa.}$$

The current flowing in the circuit is thus 37.4 μa, or 12.6 μa below the maximum allowable meter current of 50 μa.

If resistors are connected in parallel, then the total resistance is less than the lowest value of resistance in the parallel circuit. It is desirable to shunt across the meter so that R_1 (fig. 1B) may be used as a control resistor, leaving the shunt to divert some of the excessive current from the meter. This, in effect, makes a series-parallel circuit. R_1 is the series control resistor, and R_2 a 200-ohm shunt resistor; along with R_3, the meter resistance forms the parallel circuit.

To determine the current across the parallel resistance, the equivalent resistance of $R_2 + R_3$ is found by using the reciprocal of the reciprocals formula where:

$$R_{eq} = \frac{1}{\frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_{eq} = \frac{1}{\frac{1}{200} + \frac{1}{7400}}$$

$$R_{eq} = \frac{1}{0.005 + 0.000133} = \frac{1}{0.005133} = 195 \text{ ohms.}$$

The parallel circuit $R_2 + R_3$ has an equivalent resistance of 195 ohms, and is now treated along with R_1 as part of a series circuit, so that $R_T = R_I + R_{eq}$ or $R_T = 30{,}000 + 195 = 30{,}195$ ohms.

The total current is $I_T = \frac{E}{R_T} = \frac{1.4 \text{ V}}{30195 \text{ ohms}}$ or 0.0000464 amp. X $10^6 = 46.4$ μa.

To find the current in the meter (R_3), which is a branch of the parallel circuit, determine the voltage across the circuit from the equivalent IR drop; then divide this voltage by the resistance of R_3, the meter element.

$$E = I_T R_{eq}$$

$$E = 0.0000464 \text{ amp. X } 195 \text{ ohms}$$

$$E = 0.009 \text{ volts, then:}$$

$$\text{meter current } I_M = \frac{E}{7400 \text{ ohms}} = \frac{0.009 \text{ V}}{7400 \text{ ohms}} =$$

$$0.000012 \text{ amp. X } 10^6 = 1.2 \text{ μa.}$$

Thus, 1.2 μa will be the needle deflection on the recorder.

Semiconductors

A semiconductor may be described as a material with an electrical conductivity between that of a metal and an insulator; i.e., between extremely high and almost no conductivity. Its conductivity increases as the temperature increases, whereas with a metal, the conductivity decreases as the temperature increases. Each semiconductor described here may be thought of as a variable resistor in which the resistance to flow of current changes with the corresponding change of the physical environment; e.g., the increase or decrease of light, temperature, or pressure, as described in this paper (figs. 7 and 8). Humidity is not considered since a really efficient solid-state device dependent on humidity has not yet been developed.

From the above definitions it is apparent that if a solid-state semiconductor is substituted for control resistor R_1 (fig. 1), then this substituted resistance will vary the current flow in the meter or recorder according to its resistance change, which is dependent on the environment. R_1, instead of being a 30,000-ohm, manually operated, variable potentiometer, then becomes an environmentally operated resistance. Usefulness of such environmentally controlled circuits to the insect ecologists is multifold.

Solid-state, resistance-control mechanisms are classified according to the environmental factor upon which they are dependent, and also according to physical properties. They are here grouped into the following categories:

Photoconductive Cells.--Photoconductive cells are cells in which the electrical resistance varies inversely with the intensity of light that strikes the active substance. Many such cells are commercially available today. They are sometimes called light-dependent resistors (LDR) and are usually made of thin layers of selenium, silicon, cadmium sulfide (CdS), thallus sulfide, galena crystal, lead telluride, and lead sulfide. Such cells require a supplementary voltage source, and have good infrared sensitivity and high signal-to-noise ratio. They do not, however, have the excellent frequency response of vacuum phototubes (Mark, 1956). Moisture is also a major inhibitor of photoconductors, and destroys conductivity (Zmuda, 1962). The best known solid-state photoconductor is the cadmium sulfide cell (CdS), used today in many camera light meters. These cells have reached a high degree of development within the last few years, and are excellent light-control mechanisms. Below 5000 Å, the photoconductivity of CdS remains constant down to 2500 Å. But, unlike most photoconductors, infrared illumination tends to quench the photoconductivity above 5200 Å. Such cells are also remarkably sensitive detectors of X-rays and corpuscular radiation. A transport of 10^6 electrons has been demonstrated for a single X-ray quanta (Zworykin and Ramberg, 1949).

Photovoltaic cells.--Photovoltaic cells are cells capable of generating a voltage when exposed to light radiation. This category includes the selenium cells now used in such diverse applications as colorimeters, lighting controls, and relay circuits (Sasuga, 1962). Another type of cell that fits the photovoltaic definition more closely than selenium cells is the silicon or solar cell, commonly used in banks as battery cells for satellites. A silicon cell can convert sunlight directly into electricity and thus, when used with a highly sensitive relay or meter, requires no supplementary power source.

Thermistors.--Thermistors are substances in which the electrical resistance varies inversely with the temperature. They are solid-state semiconductors formed from ceramic materials made by sintering mixtures of metallic oxides, such as manganese, nickel, cobalt, or uranium (Thermistor Manual, Anonymous, 1962). Thermistors can be used either to control or measure temperatures, and they attain considerable advantage over ordinary thermocouples in that neither polarity nor lead length affects their operation; also, no reference temperatures or cold junction compensations are required, as is the case with thermocouples. Their high sensitivity, fast response, and small size make them extremely useful to entomologists concerned with measuring and controlling microenvironment of small insect cages. The thermistor's wide resistance change per degree change in temperature produces excellent accuracy of measurement; i.e., 78 ohms per degree centigrade compared with only 7.2 ohms for a platinum resistance bulb (Anonymous 1962).

Micro-ducers.--Micro-ducers are solid-state transducers which vary in resistance over a wide range with a change in force or pressure. Rare earths are processed with zirconium tetrachloride to produce resins, which undergo a change in resistance with a change of pressure (Hefferline et al., 1960). Resistance changes are not affected by temperature variations from -20° to 300° F., and the transducers' reliability is not impaired by continuous usage. Clark Electronics Laboratories[1/] produce a pressure-sensitive paint from which hundreds of pressure transducers can be made for experimental purposes. They are applicable to measurements in the fields of motion, speed, density, vacuum, or pressure, and can operate relays and circuits without amplification. They will operate from either a.c. or d.c. voltage.

Circuits

Inexpensive recording and control circuits, that have been successfully used in studying ecology and behavior of the corn earworm, are shown in figures 1 to 6. Variations or modifications of these circuits are found in the references at the end of this paper, and entomologists will no doubt devise many new uses. It is recommended that researchers interested in instrumentation obtain the publications listed (many of which are free from the manufacturers) and make up an instrumentation looseleaf handbook.

The series circuit (fig. 1A) may be converted to a simple thermistor circuit by the substitution of the appropriate thermistor for the manual variable-control potentiometer R_1. The battery, thermistor, and microammeter (R_2) or microamp-recorder form a simple series circuit. The thermistor may be mounted at extreme distances from the circuit and recorder; e.g., up among the leaves of a tree. The thermistor should be of high resistance, preferably above 100,000 ohms. Because of the high resistance, as long as the voltage remains constant, the current flow will be determined only by the thermistor temperature, and any change in the resistance of a long transmission line due to ambient temperature will be negligible (Anonymous, 1962). The author and Mr. V. J. Valli of the U.S. Weather Bureau have used this type of circuit to continuously record temperatures in the corn silk channel where the corn earworm feeds.

A bridge circuit may be constructed to form an even more sensitive temperature-measuring circuit (Taylor, 1952). Besides temperature measurements, the Thermistor Manual (Anonymous, 1962) lists the following diverse uses for simple thermistor circuits: Temperature compensation, temperature control, liquid level measurements, time-delay circuits, remote control, switching, power measurements, voltage control, altimeters, and thermal-conductivity instruments. Thermistors come in many sizes and shapes, and are thus easily fitted into various insect-cage designs. Disks, washers, beads, glass probes, rods, matched pairs, and probe assemblies are a few of the many configurations obtainable (fig. 8). Most manufacturers stock mounting hardware, and mount configurations for various types of thermistors.

Since the resistance of the thermistor is a function of its absolute temperature, excessive electrical current will heat it above the ambient temperature, causing a resistance drop. For this reason, thermistors are tested with very minute currents so that there will be no measurable increase in the thermistor temperature. The values obtained are designated by the mathematical expression R_0, and R_0 values are usually given at a specified degree centigrade in the

manufacturer's table of thermistor stock. Resistance curves for various degrees centigrade are also furnished.

Figure 2 illustrates an inexpensive actinometer using a photoconductive cell for continuous recording of moonlight, daylight, or low-intensity, crepuscular light (Callahan, 1964). The cadmium sulfide cell (CL 505L) is the control resistance which, when dark, offers so high a resistance that very little current flows in the recorder. As the cell is illuminated by more and more moonlight or the rising sun, resistance drops, and higher currents reach the recorder. The CL 505L has a light resistance of about 1500 ohms and a dark resistance of over a million ohms. The values for the shunt resistors R_1 and R_2 were determined by using Ohm's law. They are variable trimmer resistors so that values for extremely low or high light intensity can be inserted in the circuit. This same circuit illustrates a use for the photovoltaic cell. The B10 is a photovoltaic solar cell and operates a sensitive Sigma ® 1/ 5ss 50-ohm relay, which cuts in and opens the circuits when excessive sunlight reaches the cell. This prevents damage to the recorder, which would draw excessive current under high-intensity light conditions.

The basic circuit without the protective sun cell device, but with a prism over the CdS cell, is shown in fig. 9 as a dew recorder. A low-intensity light source (a) is fixed at a far enough distance above the glass prism surface (b) so that there is no heating of the prism. As moisture droplets form and disappear from the glass surface, light is reflected in all directions, which breaks up the base line of light. Figure 10 shows a recording of both moonlight (which took the place of a fixed-light source in this test) and the formation of dew along the moonlight base line. The recording can be seen rising at about 12:10 a.m. as the moon tops some trees. The dew is represented by the broken dotted portion of the moon base line, and can be seen from 12:35 to 1:05 a.m. and from 1:30 to 2:10 a.m.

Figure 3 illustrates a further use for such a circuit. A leaf is taped above the prism, and a first-instar larva confined on the leaf to feed. A red filter may be used to subdue the light. As the larva feeds, the leaf tissue decreases and more light reaches the CdS cell, giving both a time and quantity line on the recorder. This particular modification is extremely useful for very small larvae.

Figure 4 illustrates the use of a Delco ® 1/ LDR25 high-wattage CdS cell as a motor speed control. The 3000-ohm rheostat can be used to turn down the light bulb, increasing the resistance of the LDR25, and slowing the motor. Various filters could also be used between the light source and the cell and rotated by a clock mechanism, causing the motor to slow down or speed up at various set, predetermined times. Almost any load could be substituted for the motor and controlled by changing light intensity through the rotating filters. A further use of such a high-wattage, CdS cell might be to hook it in series with a cage light so that the intensity of an incandescent lamp in the cage would vary proportionally to outdoor light shining on the cell.

I am at present constructing flight-activity cages in which the light is continuously and gradually dimmed as the sun goes down. This enables me to compare continuously varying light as it is found in nature, with the on-off light situations that are usual in the study of diapause, et cetera. I believe that the on-off light situation subjects the adults to a "light shock" phenomenon that affects flight patterns and behavior of the adult earworm moth. It is only

by gradually increasing and decreasing the light intensity in the cage, and at the same time recording the variations with the actinometer that natural light behavior patterns can be compared to the on-off light patterns of a restricted laboratory situation.

Figures 5 and 11 show a circuit that is used in a moth-activity and flight-behavior chamber designed by the author. It is a circuit adapted from the International Rectifier Corporation's Solar Cell and Photocell Handbook (Sasuga, 1962) and is a transistorized relay switching circuit that utilizes an A15 selenium photovoltaic cell. The Photocell Handbook gives many simple transistorized circuits that can be easily wired, and would be useful to insect behaviorists in diverse experimental situations.

The 50,000-ohm, washer-type, variable potentiometer (fig. 5) was constructed from pressure-sensitive paint; it is possible to set the operating threshold of the circuit by tightening the nut and bolt on the washer transducer. The 500,000-ohm rheostat is a positive feedback resistor that balances the circuit for sharp switching action and suppression of spurious oscillations. The photocell is shown hooked up for switch-on with illumination, but by simply reversing the photocell leads, switch-off may be accomplished with illumination. The circuit is excellent for moth activity recordings, as the circuit is sensitive down to 1/2 foot-candle, which is well within the flight tolerances of almost all night-flying moths. Since the circuit is transistorized, it is small enough so that several can be mounted on the side of an activity chamber. The fast thyratron-like action of the circuit makes it valuable for counting and timing flights with an operational recorder. I have used it with a red filter over the light source to monitor a feeding station and take flight photographs of moths (fig. 12). Two or more cells may be mounted at either end of a flight chamber to count and time visits of moths to food or oviposition and sex-attractance sites, thus making an automatic olfactometer of the chamber. Since it is battery operated, it can be used to record moth visits to flowers in the field.

The Amprobe recorder (fig. 9d) may be used as both a galvanometer-type recorder and operation recorder by mounting an inexpensive marking pen stylus relay above the pressure-sensitive paper. With this system, both varying light and time of flight can be recorded from the flight chamber on the same recorder. It is only necessary to hook a low-voltage, battery-operated relay across the contacts of the 1000-ohm control relay, and adjust the marking pen so that it strikes down, leaving a dot on the recorder paper.

Figure 6 shows a simple circuit for recording pressure parameters by positioning a micro-ducer between the wings of a moth in fixed flight. A pressure-sensitive-paint micro-ducer is mounted over the back of the insect, and as the wings come together against the contact sides, a resistance change occurs in the circuit and is recorded in microamperes on the recorder. The author is still experimenting with this circuit. As Hefferline et al. (1960) point out, the mounting of such transducers is a difficult problem, and to eliminate error, they must be positioned so that the contactors (i.e., the wings) strike the circuit at the same position and angle. Further experimenting with pressure-sensitive paint may produce a reliable wing-pressure transducer.

The pressure-sensitive paint is applied between two metal conducting surfaces, and may also be vacuum-coated to form a barometric pickup, or placed

over a magnet with a soft iron contact on top to make a solid-state relay, amplifier, or wind- and water-pressure indicator. The manufacturer lists some of the following possibilities for imaginative experimenters: Measuring mechanical force, motion, pressure, altitude, vacuum, strain, shock, impact, acceleration, position, flow, vibration, weight, or thrust. It also has possibilities for uses in automation, such as in the development of a solid-state relay for use with counters, et cetera. The manufacturer makes several different types of paints from 0 to 1 p.s.i., up to 0 to 100,000 p.s.i. Transducers are also obtainable already mounted between disks or washers with the leads soldered in place. As pointed out above, I have used a washer-type transducer between a nut and bolt as a screwdriver-adjustable potentiometer in the photocell circuit.

There appears to be unlimited uses for such solid-state pressure mechanisms, and since they require no amplification in most cases, it may be possible to construct inexpensive apparatus for the study of moth aerodynamics. I once tested the holding ability of corn earworm moths on different surfaces (Callahan, 1957) and the technique developed in that work might be improved by using such a pressure transducer as a strain gage to more accurately measure the clinging force of the moth on the surface.

The examples listed above are but a few of the many possible uses of simplified semiconductor circuitry applicable to the study of insects. These circuits are only as reliable as their voltage source. For most uses a battery will suffice, providing it is constantly checked for stability and voltage. The 1.4-volt, button-type, mercury battery is excellent as a voltage source for most of the circuits. An on-off switch should be included in all circuits, as continuous discharge will soon cause erratic recordings and require recalibration of the circuit. Where long-period recording or continuous operation is desirable, a low-voltage, efficiently regulated d.c. rectifier power supply may be required. Many such stable rectifier circuits are given in the book, Metallic Rectifiers and Crystal Diodes, by Conti (1958).

Read-out of circuits may be direct in microamperes, or it may be preferable, as in the case of light, to convert microamperes to langley or foot-candle units. Such calibrations may be made against a standard pyrheliometer or foot-candle light meter (Callahan, 1964) and the calibration curve kept with the recorder. For a list of conversion factors from unit to unit, the reader is referred to the booklet, Conversion Factors, published by the Sillcocks-Miller Company.[1/] Photometric units are completely defined in chapter 1 of the International Rectifier Corporation's Solar Cell and Photocell Handbook.

It is hoped that this summary of semiconductor circuitry and its usages in insect ecology and behavior will induce more entomologists to use the fine electronic tools now available to biological scientists in conducting their research.

REFERENCES CITED

*Anonymous
[n.d.] Conversion factors. The Sillcocks-Miller Co. Maplewood, N.J. 16 pp.

*Anonymous
1962. Thermistor Manual. Fenwal Electronics, Inc. Framingham, Mass. 20 pp.

*Anonymous
1964. Micro-ducers. Clark Electronics Laboratories. Bul. 316, pp. 1-5. Palm Springs, Calif.

*Aronson, M. H.
1962. Recorder Manual. Instruments Publishing Co., Pittsburgh, Pa. 65 pp.

Callahan, P. S.
1957. Oviposition response of the corn earworm to differences in surface texture. Kansas Ent. Soc. Jour. 30(2): 59-63.

*Callahan, P. S.
1964. An inexpensive actinometer for continuous field recording of moonlight, daylight, or low intensity evening light. Jour. Econ. Ent. (In press.)

Callahan, P. S.
1964. A photoelectric-photographic analysis of flight behavior in the corn earworm, Heliothis zea, and other moths, with special reference to a theory for electromagnetic radiation as an attractance force between sexes. (In manuscript.)

*Conti, Theodore.
1958. Metallic rectifiers and crystal diodes. John F. Rider Publisher, Inc. New York. 152 pp.

*Hefferline, R. F., Birch, J. D., and Gentry, Thomas.
1961. Simple transducers to detect or record operant amplitude. Jour. Expt. and Analyt. Behavior 4(3): 257-61.

*Mark, David.
1956. Basics of phototubes and photocells. John F. Rider Publisher, Inc. New York. 128 pp.

*Sasuga, John.
1962. International Rectifier solar cell and photocell handbook. International Rectifier Corp. El Segundo, Calif. 111 pp.

*Taylor, J. G.
1952. Thermistors. Agr. Engin. 33(8): 502.

*Zmuda, E. I.
1962. Applications of the photoconductor. Sylvania Electric Products, Inc., Electronic Tube Division, Teterboro, N.J. 9 pp.

*Zworykin, V. K., and Ramberg, E. G.
1949. Photoelectricity and its application. John Wiley and Sons, Inc. New York. 494 pp.

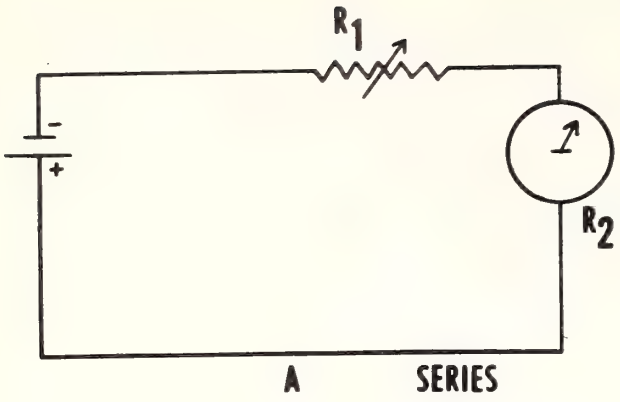
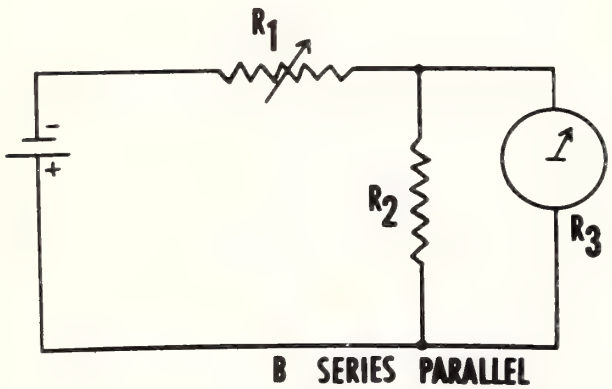


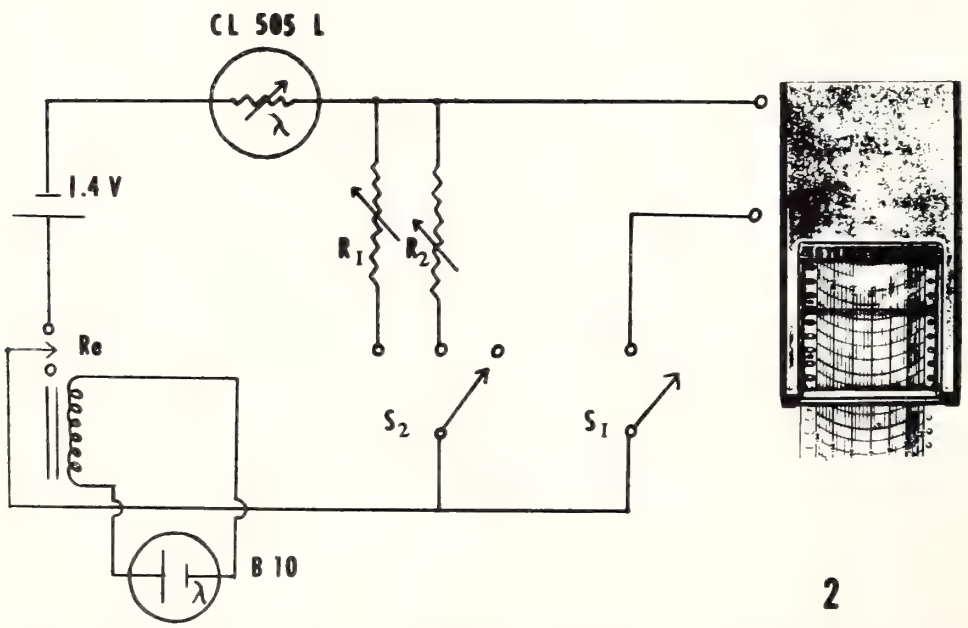
Figure 1.--Series and series parallel circuits.

A. R_1 = manual variable potentiometer (30,000 ohms); R_2 = microammeter or microampere recorder (7400 ohms).

B. R_1 = manual variable potentiometer (30,000 ohms); R_2 = shunt resistor (200 ohms); R_3 = microammeter or microampere recorder (7400 ohms).



1



2

Figure 2.--Actinometer or dew recorder circuit. CL505L = cadmium-sulfide cell; R_e = Sigma 5ss 50-ohm relay; B10 = International Rectifier selenium sun cell; R_1 = 0-50 ohm, trimmer potentiometer; R_2 = 0-500 ohm trimmer potentiometer; S_1 = 3 position shunt switch; S_2 = on-off switch.

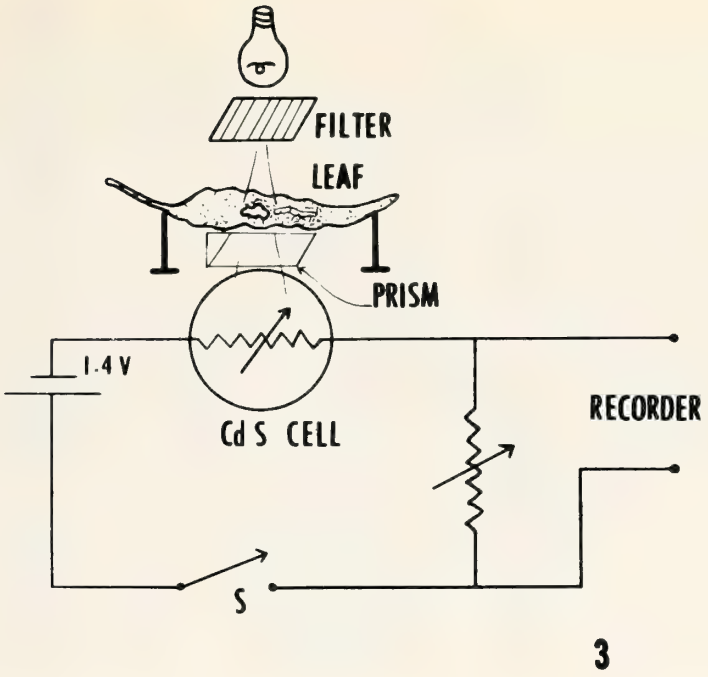


Figure 3.--Larval leaf-feeding recorder. Same as figure 9, dew recorder with leaf over prism.

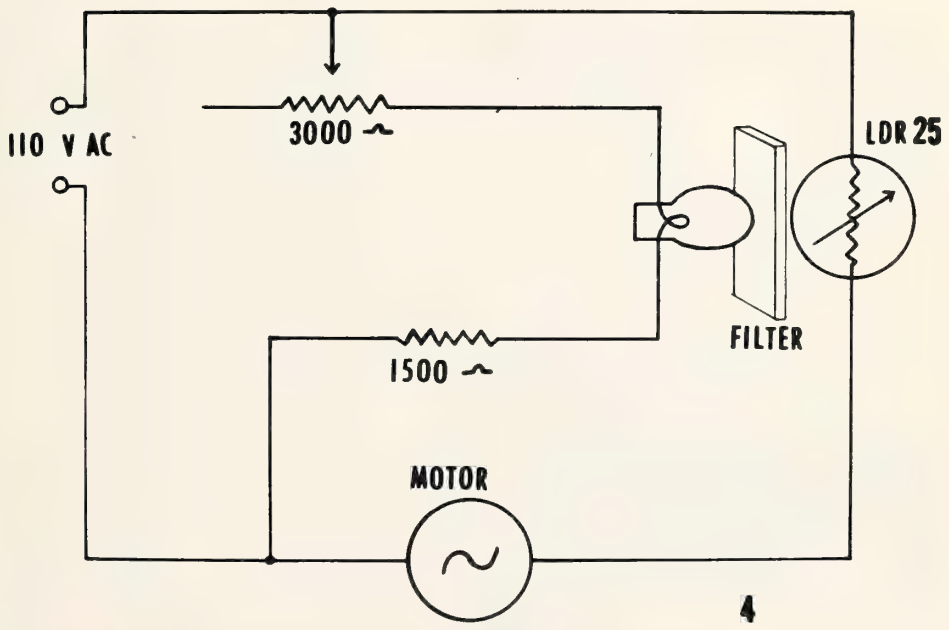


Figure 4.--Control mechanism for motor or other electrical load, using a 25-watt, Delco, cadmium-sulfide cell.

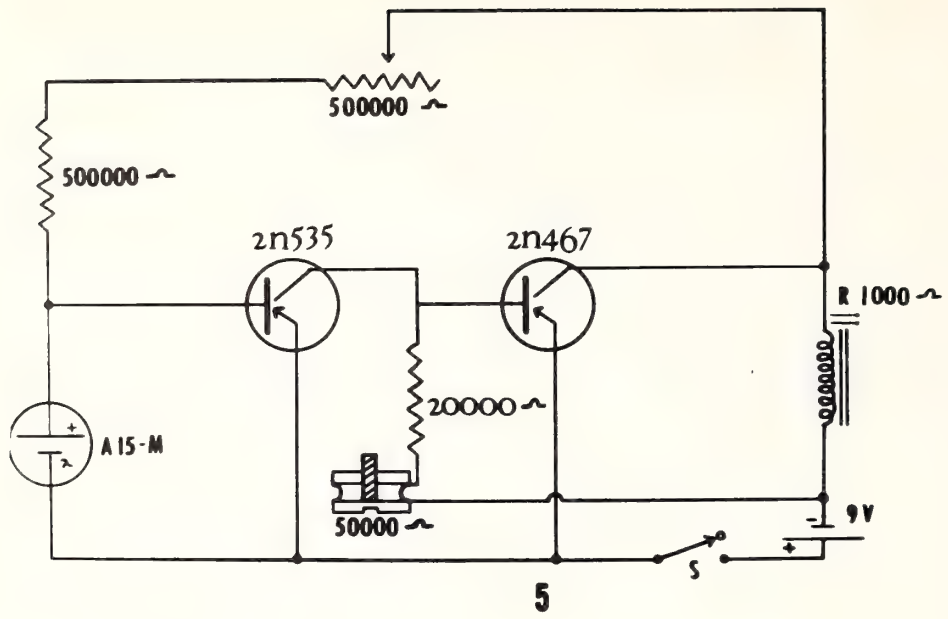


Figure 5.--Two-transistor control relay, utilizing an A 15-M selenium photovoltaic cell for the light control.

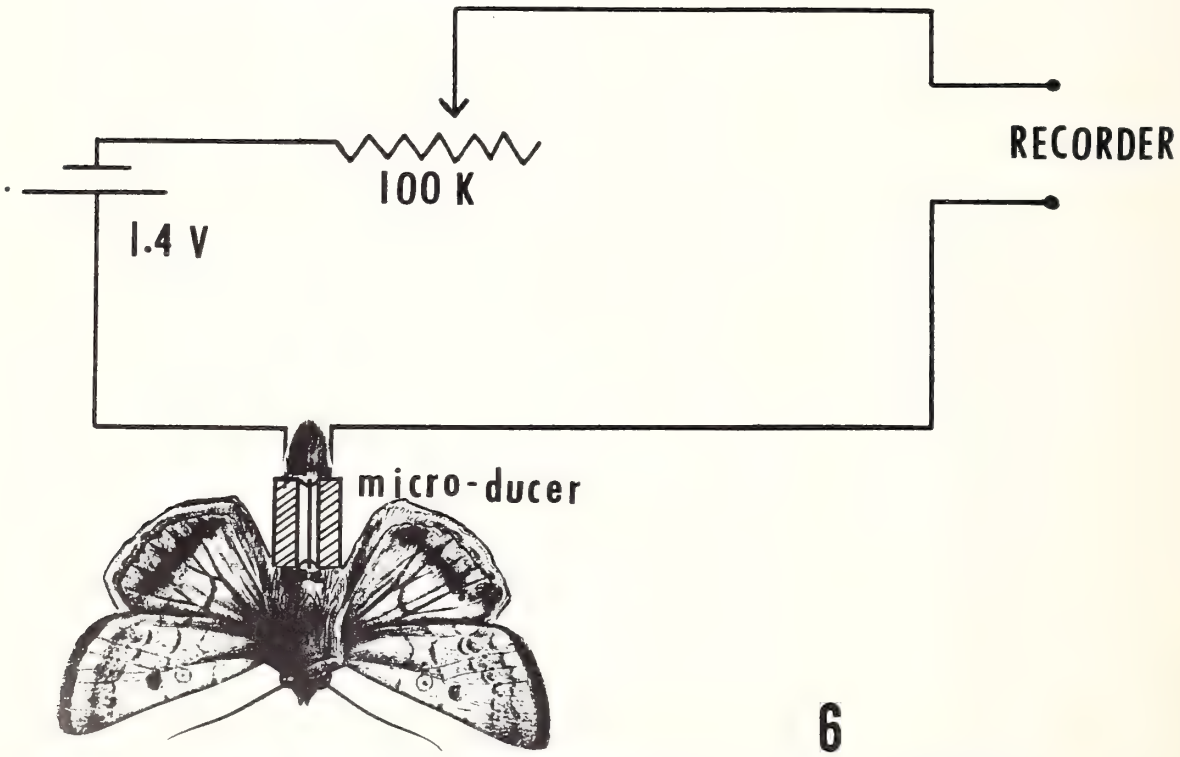


Figure 6.--Micro-ducer pressure-sensitive transducer mounted between a corn earworm moth's wings to record force of wing beat above back. The 100,000-ohm, variable rheostat allows for calibration of range extremes on the recorder.

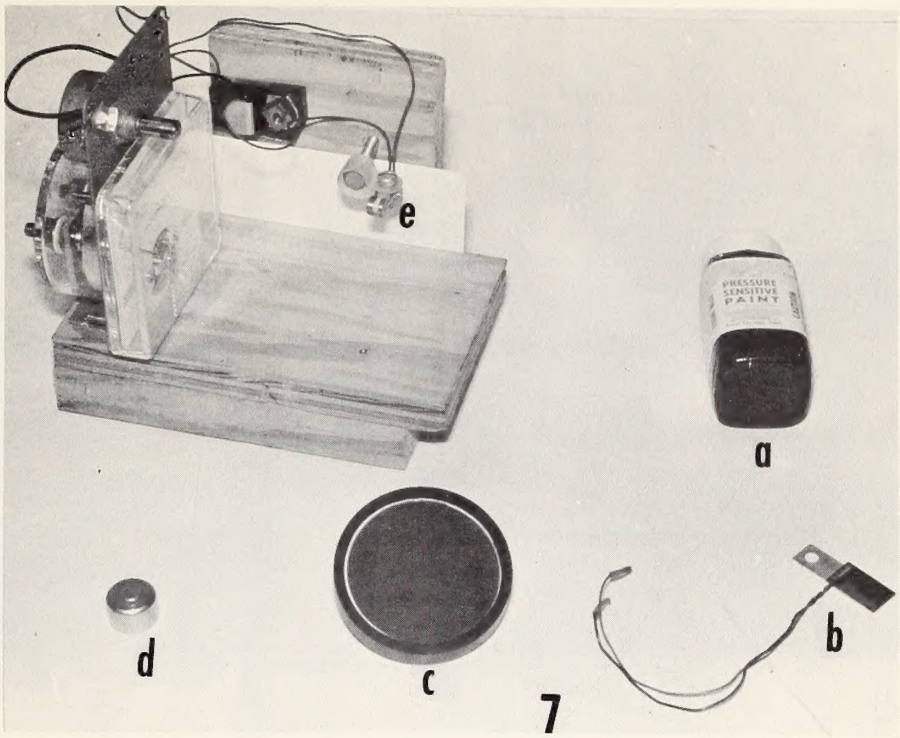


Figure 7.--(a) Bottle of pressure-sensitive paint; (b) B2M International Rectifier selenium sun cell; (c) A 15-M selenium photovoltaic cell; (d) 1.4-V. button mercury battery; (e) pressure micro-ducer mounted in series circuit with rheostat, battery, and microammeter.

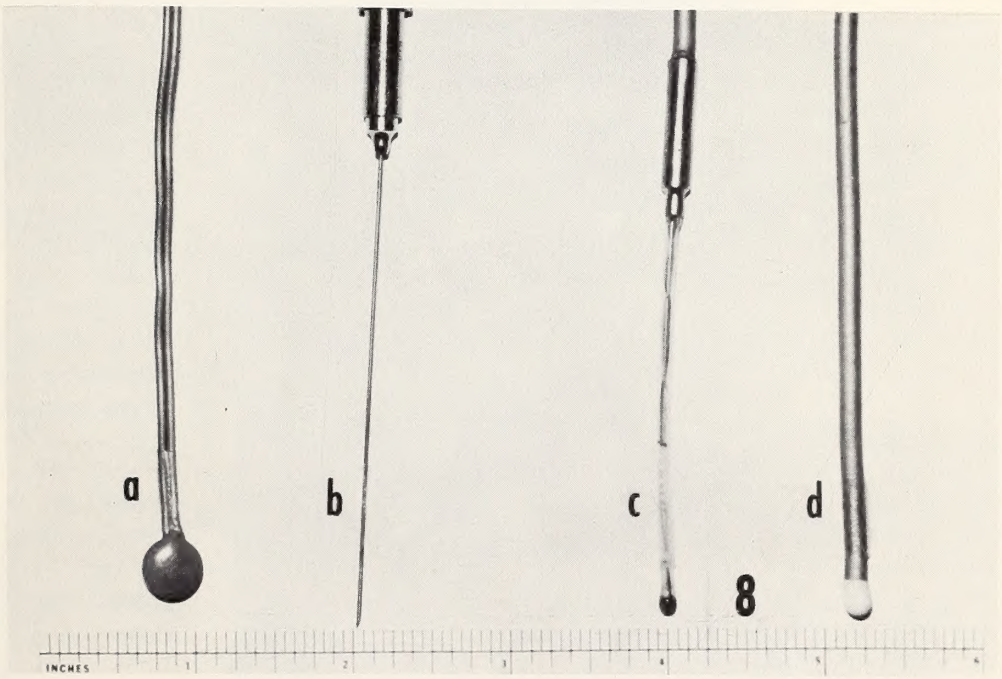


Figure 8.--Thermistor configurations. (a) Disk thermistor for surface temperature measurements; (b) hypodermic-type thermistor, used in corn silk channel by the author; (c) flexible probe; (d) bead probe.

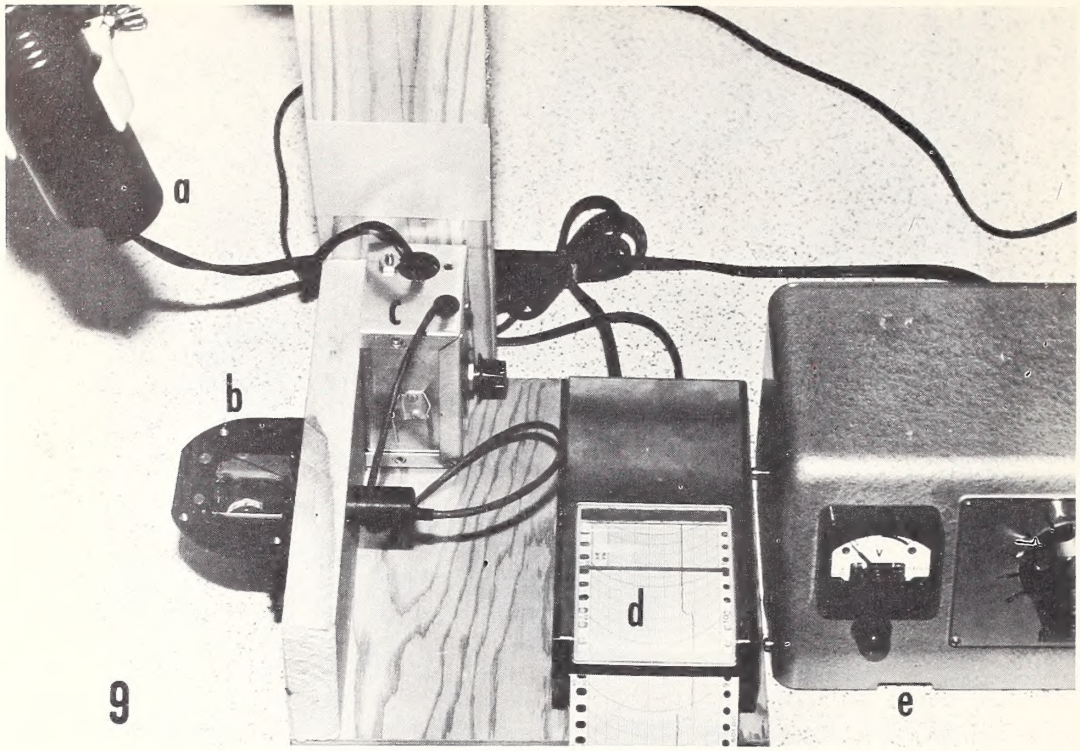


Figure 9.--Dew recorder, circuit No. 2 with prism over the CdS cell. (a) Fixed light source; (b) prism; (c) circuit; (d) Amprobe 7400-ohm, 0-50 microampere recorder; (e) adjustable transformer for light source.

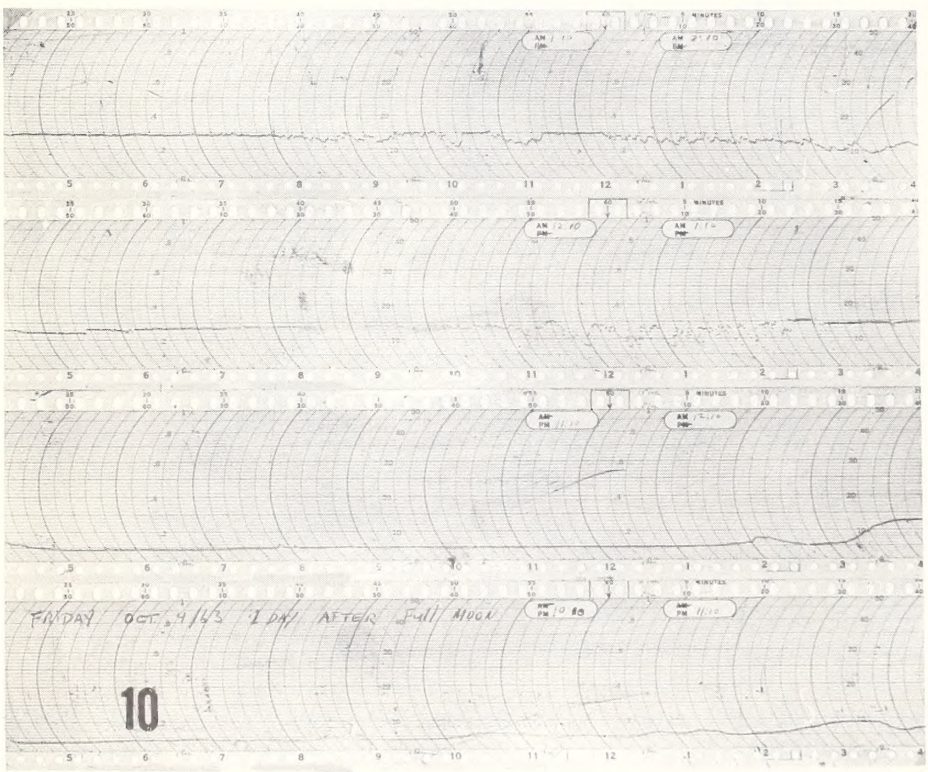


Figure 10.--Recording of dew formation on night of Oct. 4, 1963, from 10:10 p.m. (bottom strip) to 2:10 a.m. (top strip). The line represents moonlight and not a fixed light source. The rise in the line at 12:05 a.m. represents the moon climbing above the trees. Dew is represented by the breaking up of the line. The first period (3rd strip) lasts for 30 minutes from 12:35 a.m. to 1:05 a.m., and the second longer period (top strip) from 1:30 on.

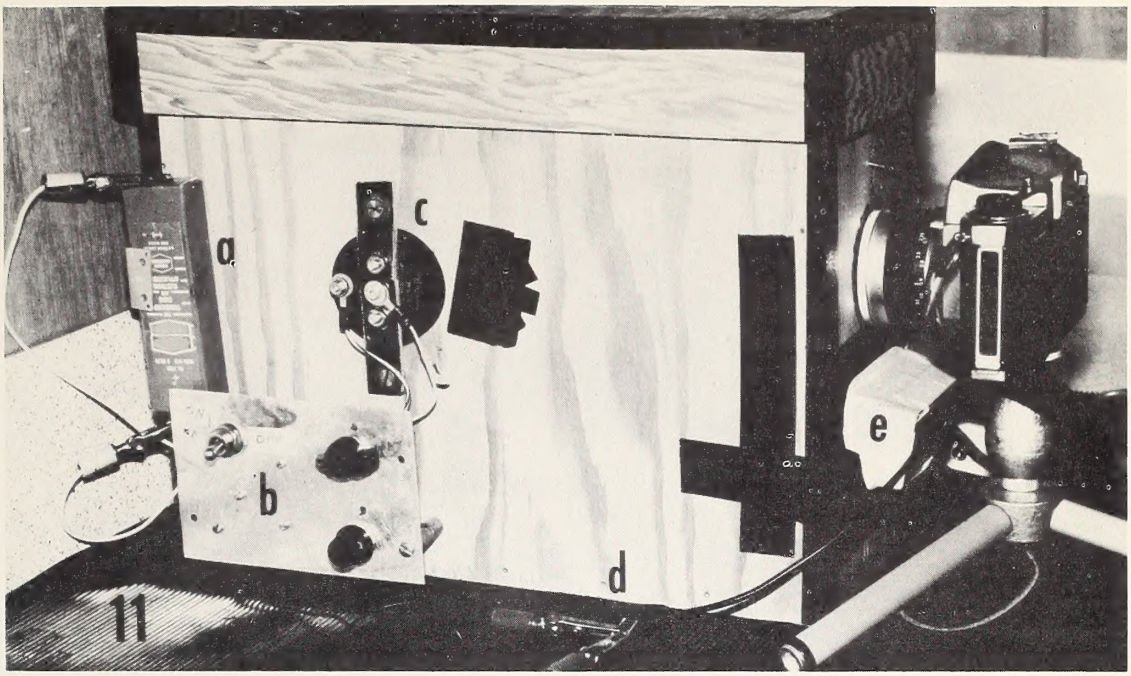


Figure 11.--Flight chamber for studying moth aerodynamics. (a) 9-V battery; (b) circuit (fig. 5); (c) A 15M selenium cell; (d) connection of strobe light; (e) across relay contacts of the Sigma 11f, 1000-ohm relay of circuit (fig. 5).

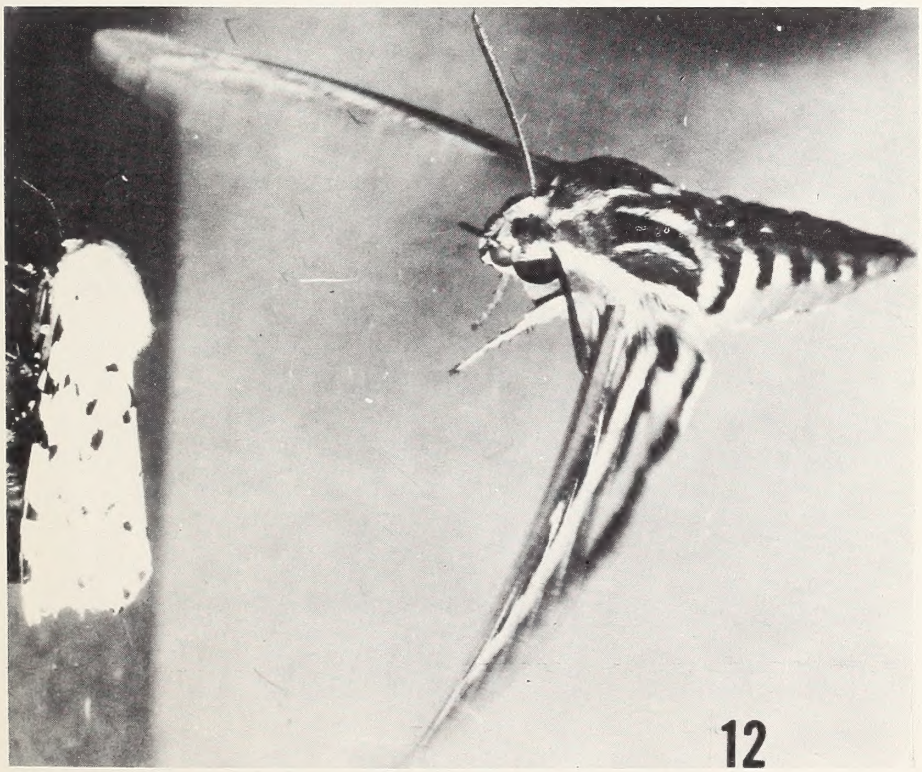


Figure 12.--White-lined sphinx in a banking turn. The low-intensity red light beam crosses from the right and focuses on A 15M cell at left. Although the light intensity is low, the strobe fired even though the cell was partially blocked by an arctiid. Because the cell operates at low light levels, the camera shutter is left open and the film does not become fogged. The strobe light alone takes the picture. (Callahan, 1964).

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
BELTSVILLE, MARYLAND 20705

Official Business

Postage and Fees Paid
U.S. Department of Agriculture